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SELF CONSISTENT SCHEME FOR OBTAINING ELECTRON/POSITRON COLLISIONS WITH MULTI-TEV ENERGY

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Abstract

We describe here a self-consistent scheme for arrangement of multi-TeV collisions of e^+e^- by using a laser burst swept along microstructures with stable rate of acceleration ~10GeV/m. Shown that all component of the scheme are within present day technology. For energy ~1TeV luminosity could reach 10^{35} with wall-plug power of few tens of kW only.

INTRODUCTION

In simplest interpretation, the meaning of self consistence adopted for our purposes is a possibility to build something with technology available at the time of proposal. Technology might be at hand in general, so with necessary funds one can buy it on the market. Parameters for the scheme must be below all technical restrictions and of cause far apart from physical limitations applicable to every component of such device.

So, we believe, the phonograph invented at the end of nineteenth century could be a self consistent device even during time of ancient Egypt. Writing sounds (words) on a wooden plates covered by beeswax or clay tables was a common procedure. So if somebody could show this device at those times, I think it would be not a problem *to fabricate* (make) a working copy with technology available there. Jewellery can serve as a reference for fine work possibilities. One can agree that the steam engine could be a self consistent device at the times of Rome Empire. Usage of this kind phenomenon for transportation could be demonstrated also: just if one could make a belt from rotating sphere to the wheel in a famous toy developed by Hero. Delta-wing and even some simple electrical elements also can fulfil the list. One can easily add to this list. So our goal was to find *such* a scheme for acceleration of charged particles, which can be realized at present days with technologies available on the market.

RF acceleration of charged particles means that particle acquires *many* RF photons during the acceleration process. Some time required while engineers working in accelerator physics recognized that one of the photons in Feynman's two-photon diagram associated with the wake field, as they called it (I am not sure that people working with plasma methods of acceleration can tell where this second photon hidden in theirs methods, however). So this second photon is crucial agent in all business. Presence of this (radiated) photon allows, for example, particle acceleration by the plane wave; the process is going while particle re-radiates. In terms of photon absorption, the cross section of this process decreases with energy $\sim 1/\gamma$ preventing usage of this method at high energy.

The scheme we are proposing [1]-[3] contains accelerating structures scaled down to a micrometer level. Excitation of each cell of the structure is going from the side through side opening. One can say that *each* cell has a tiny input waveguide attached from the side. So this scheme which realizes the method uses new micro technology required for fabrication of such structures.

High gradient required by the necessity to keep the ratio of wakes to acceleration field at reasonable level. Accelerating structure serves for *confinement* of EM field in space. Its precise location defined by accuracy of fabrication, accuracy of positioning, how far from equilibrium the fields are and by physical limitations. So the structure can not be much larger, than the wavelength of laser radiation, otherwise the fluctuations in a process of the field establishment will generate unnecessary long living (in terms of period) perturbations with undesirable spatial structure. That is why we think that so called photonic structures are useless for particle acceleration. Also, a small structure can not accommodate thermal photons, especially if the structure is cooled down–this positive property of compact structure goes in its advantage.

Primary element of the scheme is the source of low emittance beam. We showered that wiggler dominated ring can satisfy requirements. Events at IP are going in deep quantum regime. Luminosity what can be achieved is far beyond the value suggested for ILC, hiving significant safety margins for reduction of the bunch population.

PRINCIPLE

Basically the problem with laser acceleration is in ability of materials to withstand the intense radiation. Experiments done show that the limit to damage is strongly dependent of the time of illumination; shorter the illumination time—higher density is allowable. For example, in [4] reported the density measured 6 J/cm^2 for 1 *ps* pulse duration and 10 J/cm^2 for 0.3 *ps* pulse. From the other hand if one suggests a structure, having length, say 3*cm* long the pass-time through this structure going to be $\tau \cong L/c \cong 100$ *ps*. So idea emerged to illuminate (excite) only the part of structure, where currently the beam is located. We would like to specify here that the bunch is going inside the structure, pretty much as it is going inside usual RF structure. Only peculiarity here is that due to small dimensions, the laser radiation introduced into the each cell separately from the side hole.

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We proposed in [1] a method on how to arrange this local excitation, Fig.1. This is done by device, which makes sweep of focused laser radiation along the accelerating structure and called this procedure Travelling Laser Focus (TLF). Sweeping device could be characterized by deflection angle ϑ and by the angle of natural diffraction $-\vartheta_d \cong \lambda / a$, where a –is the aperture of the sweeping device which is o the order of the transverse laser beam size (Fig.1). The ratio of deflection angle to diffraction angle is fundamental measure of the quality for any deflecting device**.** This ratio defines the number of resolved spots (pixels) placed along the structure, $N_R = \vartheta / \vartheta_d$. The last number is an invariant under optical transformations. Basically this number shows how many separated (resolved) focused spots this sweeping device can allocate along the accelerating structure. For laser radiation with the wavelengths $10\mu m \geq \lambda_{ac} \geq 1\mu m$ the number of resolved spots can be within 20-200.

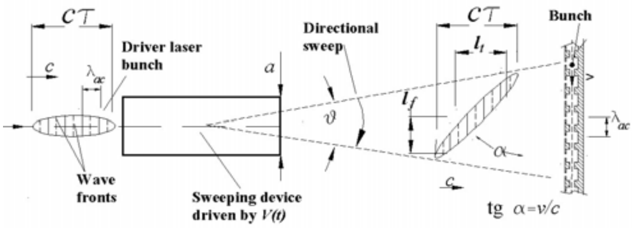

Figure 1: TLF principle of preparation of sloped laser bunch with the sweeping device.

The focal point of the laser beam is following the beam *in average*. Power reduction and shortening of illuminating time is equal numerically to the *number of resolved spots* (pixels), associated with the sweeping device. The number of accelerating cells excited simultaneously is $\sim l_f / \lambda_{ac}$, where $l_f \sim 100\lambda_{ac}$ is a spot size along the structure, Fig.1. Accelerating cells in a structure separated in longitudinal direction with distance λ_{ac}, so an electromagnetic field is in phase inside each cell. A cylindrical lens serves for the focusing of laser radiation in a transverse to the motion direction.

SWEEPING DEVICE

For *multiple-prism* sweeping device with traveling wave $\Delta\vartheta \cong 10^{-2}$ and $N_R \cong$ 200 can be reached, [7]. For such a sweeping device, a lot of electro-optical crystals can be used, *KDP, CdTe*, *CuCl, GaAs*, *ZnTe* [3].

Pulse generator with Inversely Recovered Diodes technique [4], [5] can be used for testing the sweeping device. Typical PS of this class operates with repetition rate up to 1MHz providing rise time down to 50 ps and voltage up to 30 kV. Size of this device is typically 350× 150× 300 mm^3. We expect that one sweeping device can feed 5-10 structures [7].

For optical triggering the filling of diode transition by carriers can be done with the help of laser pulse illuminating the diode. The second possibility lies in fast changing dielectric permittivity of switching element by the laser radiation.

The broad band traveling wave deflector uses crystals located in the middle of a waveguide. The power required for excitation of a waveguide having width $\cong 5cm$, height$\cong 1cm$, $\lambda \cong 5cm$, to the level $E_0 \cong 20$ *kV/cm* goes to be ~1.2*MW*, only [7]. This scheme has a potential to be transformed into strip-line system.

ACCELERATING STRUCTURE

The latest measurements show that the damage threshold increases while the illumination time is shortening [4]. This was explained by saturation of impact ionization rate per unit distance. *Measured* threshold for 0.3 *ps* pulse was about 10 *J/cm*^{2}. For 1 *ps* the threshold measured was 6 *J/cm*^{2}. In our proposal the laser density comes to 0.3 *J/cm*^{2}.

Example of accelerating structure represented in Fig.2. Here the covers adjust the coupling between the cell and outer space. The last defines a quality factor Q_{RF} of the structure. With these covers the height h is about $h \cong \lambda_W / 2$ and the cells have *inductive* coupling with outer space.

Calculations carried with GdfidL. The wake was found to be slightly inductive. Each structure is installed on a nano-table moved by a piezoelectric. Structures are cooled down to keep the mechanical tolerances within the margins allowed. Monocrystal of Silicon with different types of conductivity can be used here. The final conclusion could be made after experimental work in this field.

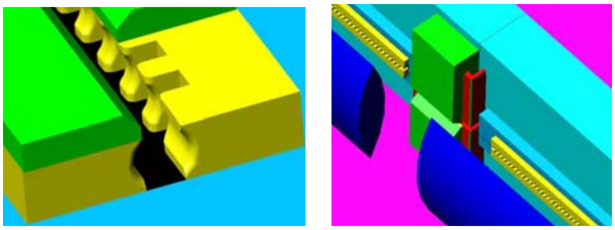

Figure 2: Structure with round passing holes, left, and the quadrupole design, right.

Possibilities in fabrication are far beyond necessary for this structure. Mostly complete description one can find in [11]. So accelerating structure made with this technology can work with a Laser source of EM Radiation with wavelengths $\lambda_{ac} \cong 1-10\mu m$.

GENERAL SCHEME

General scheme at a glance is similar to the scheme linear collider, except the length. 2× 10 TeV collider has 2× 1 km only, see [12]. Elements of the scheme located on separate platforms aligned with help of sensors, installed at the end of each platform. The sensors are similar to that used in tunnelling microscope technique. This system could be made fast enough to exclude influence of ground motion, mostly intensive at lower edge of the spectrum.

Beam prepared in a damping ring and laser beam 1 go first to the end of accelerator. Mirrors 2 redirect it back, pos.3, trough the sequence of splitters. In the similar way the particle's beam 5, goes trough bending system 6 and further trough structures to next modules, 4. 7 and 8 –are the focusing elements for the laser and particle's beam respectively. Optical platform 9 is standing on legs 10 with active damping system to minimize vibrations. 13–cylindrical lenses, 14–are the accelerating structures. All elements on the table are located in a vacuumed volume, not shown here.

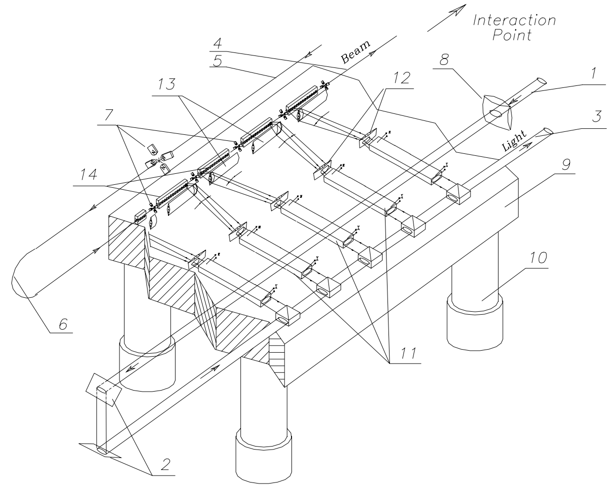

Figure 3: Accelerating table.

PARAMETERS

General parameters of the scheme are below.

Wavelength	$\lambda_{ac} \cong 1\mu m$
Energy of $e^{\pm}$ beam	2×10 *TeV*
Luminosity	10^{35}cm^{-2}s^{-1}
Total two-linac length	2×1 *km*
Main linac gradient	10 *GeV/m*
Bunch population	$3\ 10^5$
Bunch length	0.1 *μm*
No. of bunches/train	30
$\gamma\,\varepsilon_x\,/\,\gamma\,\varepsilon_y$	$5\cdot10^{-9}/1\cdot10^{-9}\,cm\cdot rad$
Laser flash energy	2×3*J*
Laser density	0.3 *J/cm*^{2}
Illumination time	0.1 ps
Length of section	3*cm*
Laser flash energy	100 μJ/section
Repetition rate	1 *kHz*
Laser beam power	2×3*kW*
Damping ring energy	2 *GeV*
Damping time	10ms
Wall plug power**	2×30 *kW*

** Without supplementary electronics.

CONCLUSION

Nano–technology available creates solid base for accelerator with *Travelling Laser Focus*. Illuminating time and total laser power reduction in this method defined by the number of resolved spots (pixels) associated with deflecting device. Lasers for the TLF method need to operate with $\tau \approx 100ps$ pulse duration. Any point on accelerating structure remains illuminated by ~0.3 *ps* only. Laser density on the surface of structure goes to be 0.3 J/cm^2. TLF method promises up to 10 *TeV/km* with 3 *mJ/m*. With such high gradients, $\mu^+\mu^-$, $\pi^+\pi^-$, $\pi p, \mu p$ and ion-ion collisions become feasible. We conclude that acceleration in a laser-driven linac with TLF method is a present day technology and no physical limitation found on this way.

Testing of this method might be a highest priority task for accelerator physics.

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REFERENCES

[1] A.A.Mikhailichenko, Author's certificate USSR N1609423, Priority May 1989, Bulletin of Inventions (in Russian), N6, p.220, 1994.

[2] A.A. Mikhailichenko, Presented at 11^{-th} AAC Workshop, Stony Brook, NY June 21-26, Ed. V. Yakimenko, CBN 04-6. Electronic version available at http://www.lns.cornell.edu/public/CBN/2004/ CBN04-6/phys_found.pdf

[3] A.A. Mikhailichenko, CLNS 00/1662, Cornell 2000; Also Snowmass 2001. Full list of referred can be found there. Electronic version available at http://www.lns.cornell.edu/public/CLNS/2000/

[4] D. Du, X. Lu, G. Korn, J. Squuier, G. Mourou, CLEO94, May 8-13, 1994, Anaheim, California, Vol.8, p.407.

[5] I.V.Grekhov, V.M. Efanov, A.F. Kardo-Sysoev, S.V. Shenderei, Pis'ma Zh.Tech.Fiz., 1983, vol.9, no 7, p.435.

[6] I.V.Grekhov, V.M. Efanov, A.F. Kardo-Sysoev, S.V. Shenderei, Solid-State Electron., 1985, vol.28, no 6, p.597.

[7] A.A. Mikhailichenko, TPAE011, this Conference. For extended version see CBN 05-6, Cornell University, LEPP, 2005. http://www.lns.cornell.edu/public/CBN/2005/CBN05-6/cbn05-6.pdf.

[8] V.L. Mikhalev, R.A. Rzaev, I.M. Ternov, Zh. Tech. Fiz. 52, 423-432 (March 1982), Sov. Phys. Tech. Phys. 27(3), March 1982. Translation of American Institute of Physics.

[9] P. Chen, K. Oide, A.M. Sesler, S.S. Yu, Phys. Rev. Lett. 64(1231-1234), 12 March 1990.

[10] I.V. Grekhov, M.E. Levinstein, V.G. Sergeev, I.N.Yassievich, JETF, 1079, V. 49, N5, pp.1013.

[11] Springer Handbook of Nano-Technology, Ed. Bhushan, ISBN 3-540-01218-4, 2004.

[12] A.A. Mikhailichenko, CBN 05-6, Cornell University, LEPP, 2005. Full version available at http://www.lns.cornell.edu/public/CBN/2005/CBN05-8/cbn05-8.pdf